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Genetic Algorithm Based Feeder Reconfiguration and Control of Reactive Power for Loss Reduction

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Abstract

Power distribution network consists of a group of radial feeders which can be connected together by several tie-switches and tie-lines. The power loss reduction in the network is a major concern of electric distribution utilities. Among conventional methods, optimal reconfiguration and capacitor placement are two effective methods which can be applied on the network. In this paper a feeder reconfiguration algorithm is build and present for the purpose of power loss reduction in distribution systems. The methodology developed combine optimization technique. The network reconfiguration problem is formulated as single objective optimization problem with equality and inequality constraints. The proposed solution to this problem is based on a general combinatorial optimization algorithm known as genetic algorithm, and the load flow equations in distribution system. The GA optimizes the system-switching pattern for losses reduction. Decides the system topology, and considered taken the size and location of capacitor placement in the radial distribution networks.

The two selection method used in genetic algorithm, first method roulette wheel selection and second method tournament selection. Tests show the different in execution time of the program to arrive the best fitness function.

The proposed algorithm has been implemented in technical MATLAB package and tested for practical network (48-bus) which is taken from the distribution system of Palestine Street in Baghdad city. Tests show that GA is suitable algorithm as optimization technique, high accuracy, and avoid local minimum by searching in several regions to arrive to the global optimum solution. Thus, the outcome of the study shows an efficient technique to solve the problem of network reconfiguration for loss reduction in the distribution power system.

Introduction

Distribution systems are the network that transports electric energy to the end user from distribution substation. These systems are radially structured and closely connected, so that widely distributed customer can be supplied. Each primer feeder includes a number of line sections, sectionalizing switches installed on line section, and other components such as tie switches, which connect two primary feeder, or two substation, or loop-type laterals [1].

Loads vary with time of day, each type of load (residential, commercial, industrial) has a different time profile, and each feeder serves a different mix of loads. Therefore, the load pattern on each feeder varies constantly, and differently. Under normal operating condition, a distribution system is operating on normal configuration, which is previously defined. However, when unexpected forced outages of lines, scheduled maintenance, overload, and fault happen, system operators reconfigure the distribution system by controlling the on/off statues of switches so that the objectives are satisfied, under the given operating conditions. This creates an opportunity to constantly keep losses at a minimum by reconfiguring the feeders during the day. Automatic switches and control systems must be installed to perform this distribution automation, at a cost that must be balanced against the savings in losses [2]. The optimal capacitor control problem is then conveniently incorporated in the capacitor design and solved in it's entirely. In practice, however, several load groups do not vary over the daily load cycle in the same manner as the rest of the system load so that prevailing load profile cannot be readily predicated. Capacitors are often installed in distribution system for reactive power compensation to carry out power and energy loss reduction, voltage regulation, system security improvement, and system capacity release [3]. The capacitor placement problem considered to determine the locations, types, number and sizes of capacitors to be installed in a radial distribution system, and the control schemes of the capacitor at Weren't load levels. The objective is aimed to reduce the energy losses in the system and retain the voltage magnitudes of the system within prescribed maximum and minimum allowable values for different load levels while minimizing the total cost of the system [4].

The early work on feeder reconfiguration for loss reduction is presented by M. E. Baran & F.F.Wu (1989) [5], present a general formulation and solution methods of the feeder reconfiguration problem for loss reduction and load balancing. K. Nara, A. Shiose, M. Kitagawa, and T. Ishihara (1992) [6], proposed the problem is a complex mixed integer programming problem and is very difficult to solve by a mathematical programming approach. Q. Zhou, D. shirmohammadi,and W-H.ELiu,(1997) [7],developed a new feeder reconfiguration algorithm for cost reduction. A. Saad (1999) [8], developed a formulation of the network reconfiguration problem for both loss reduction and load balancing. A modified simulated annealing technique been developed with the purpose to avoid being trapped in local minima, by not always taking the best choice at each step. M.A.Matos & Paulomelo (1999) [9], presents an approach to the reconfiguration of radial distribution networks, for both loss reduction and service restoration, using the same meta-heuristic tool: the simulated annealing algorithm. T. Ghose, S. K. Goswami, & S. K. Basu, (1999) [10], presents Genetic algorithm has been used to solve the problem of capacitor placement in power distribution systems. A. Augugliaro, L. Dusonchet, M. G. Ippolito & E. R. Sanseverino , (2003) [11], presents deals with the problem of optimal reconfiguration of radial distribution networks for minimum loss operation. The proposed control strategy of the open-closed status of the tie-switches is distributed, since every MV/LV node is provided with local controllers having some measured entities as input. R. T. F. Ah King, B. Radha & H. C. S. Rughooputh , (2004) [12], presents the application of a fuzzy controlled real coded genetic algorithm to solve the reconfiguration problem. L. Garcia Santander & F. Abou Chacra , (2005) [13], presented on method for minimal losses in primary distribution systems by changing topology , the loss minimization in distribution systems is based on Simulated Annealing (SA) and Radial Power Flow. R.Rajaram, K.Sathish Kumar & N.Rajasekar, (2015) [14], Network reconfiguration which is constrained nonlinear optimization problem has been solved for loss minimization, load balancing, etc. for last two decades using various heuristic search evolutionary algorithms like binary particle swarm optimization, neuro-fuzzy techniques. Manju Mam, Leena G & N.S. Saxena, (2016) [15], presents a distribution network reconfiguration based on bacterial foraging optimization algorithm (BFOA) along with backward-forward sweep (BFS) load flow method and geographical information system (GIS). In this paper the topological configuration of the network is determined by the states of tie and sectionalizing switches. The GA optimizes the system-switching pattern for losses reduction. Decides the system topology, and considered taken the size and location of capacitor placement in the radial distribution networks.

Problem Formulation

In this section problem formulation are based on the load flow equations for distribution system. The configuration with minimum losses is determined by a GA, which contains two methods of selection: "*Roulette Wheel*" selection method and "*Tournament*" selection method, with "*Elitism Technique*". The purpose of distribution network reconfiguration is to find a radial operating structure that minimizes the system power loss while satisfying operating constraints. Thus network reconfiguration for loss minimization can be formulated as follows:

Minimize, $P_{Loss} = \sum_{i=1}^{n}(Loss)i \quad i \in NL$ ….. (1)

$\therefore \sum_{i=1}^{n} I_i^2 \, R_i K_i \quad i \in NL$ ….. (2)

Minimize

$P_{loss} = \sum_{i=1}^{n}\left(\frac{P_i^2 + Q_i^2}{V_i^2}\right) R_i K_i \quad i \in NL$ ….. (3) , Where:

***NL*:** is the set of branches.

***n*:** total number of line sections.

$(Loss)i$: is loss at branch i.

V_i, R_i, P_i and Q_i: sending bus voltage, resistance, active power and reactive power of line section *i*, respectively.

ki: represent the topological status of the branches.

ki=1 if the branch *i* is closed, and ki=0 if the branch *i* is open.

Subject to following constraint [16]:

1. Radial network constraint:

Distribution network should be composed of radial structure considering operational point of view.

2. Power source limit constraint:

The total loads of a certain partial network cannot exceed the capacity limit of the corresponding power source.

3. Node voltage constraint:

Voltage magnitude at each node must lie with their permissible ranges to maintain power quality.

$V_i min \ll V_i \ll V_i \max \quad i \in NL$ ` ….. (4)

Where: N is the set of nodes, Subscripts 'min' and 'max' represent the lower and upper bounds of the constraint.

4. Branch current thermal stability constraints:

Current magnitude of each branch (feeder, laterals and switches) must lie with their permissible ranges.

$K_i I_i \ll I_{\max} \quad i \in NL$ ….. (5)

5. Kirchhoff's current laws:

$g_i(I, K) = 0$ ….. (6)

6. Kirchhoff's voltage laws

$g_i(V, K) = 0$ ….. (7)

The calculation variables include the active line power P_i, reactive line power Q_i and voltage magnitude V_i at certain buses of the distribution system. Thus, a computationally efficient control procedure for selecting the optimal configuration for a given load profile is to be developed where the input data are composed of a limited number of calculated variables.

Details of GA

A. Genetic string representation

The only parameter, which determines the minimum loss configuration, is the position of the normally open sectionalizing switches. Note that the number of positions of open sectionalizing switches is identical to keep the system radial once the topology of the distribution system is fixed, even if the open switch positions are changed. Therefore, to memorize the radial configuration, it is enough to number every open switch position, and to-memorize which switch is open corresponding to each open switch position number [6]. Since open loop radial distribution system can be depicted as a graph, as shown in Figure (1), where several sectionalizing switches are located on each branch between two bus bars, the open switch positions can be remembered by memorizing branch numbers [17].

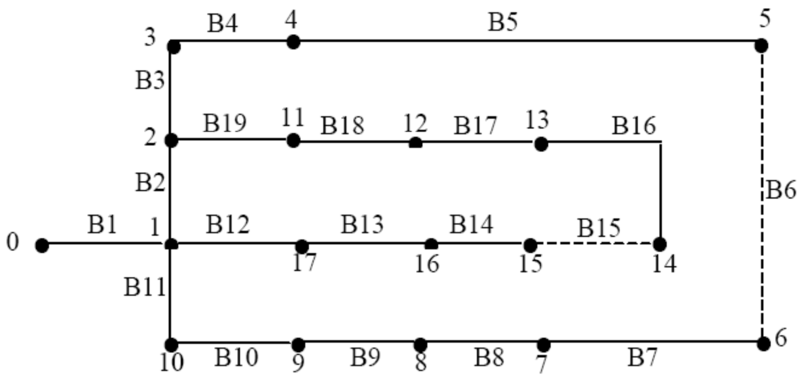

Figure -1: Graph of Distribution System Model

Then, the length of strings equals to the number of branches. Thus, the string structure can be depicted as shown in figure (2). In Figure (2), " Branch State No. (i) " means the state branch number. Where i-th switch position exists. " Branch State No (i)" is expressed by a binary code as shown in Figure (2). For ‘1’ if the branch (i) is closed, or ‘0’ if the branch (i) is open.

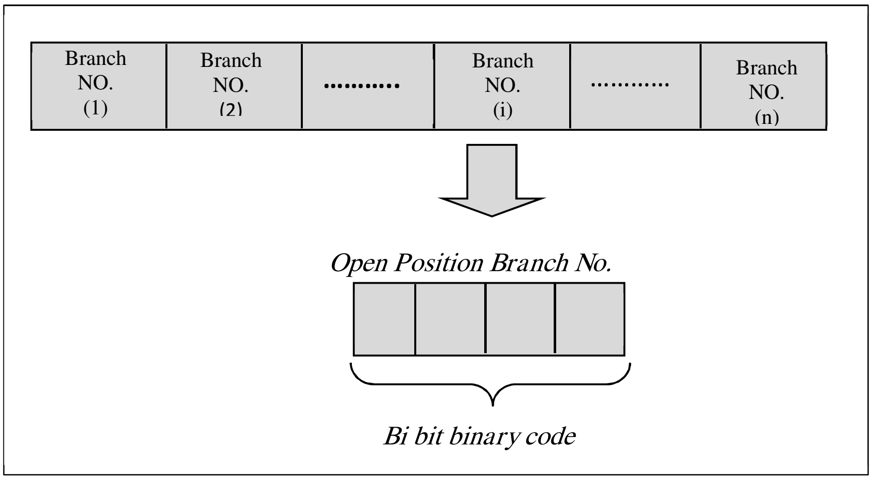

Figure -2: String Structure

In this string structure, by applying the crossover operation, it is expected that the resulting string sometimes present a loop configuration or de-energized sections. In such a case, this string is abandoned, and another mate is selected for another crossover. Using the above representation, the radial network shown in Figure (1) can be represented by string in Figure (3). The coding scheme is illustrated in Figure (3). ‘0’ indicates an ‘open’ switch and ‘1’ indicates a ‘closed’ switch. There are 17 sectionalizing switches and 2 tie switches for the 19-bus distribution system. Hence the GA encoding requires 19 bits for a chromosome string as given in Figure (3). The basic configuration of 19-bus distribution system consists of two normally open tie-switches. Tie switches s6, s15 are coded as ‘0’. The remaining 17 switches are coded as ‘1’.

B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	B15	B16	B17	B18	B19
1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1

Figure-3: The Chromosome Structure and Representation of the Network Topology

B. String evaluation “Fitness Function”

In a genetic algorithm, a fitness function is a mapping, which determines the fitness of each string in the population. The GA proceeds to evolve better-fitting strings, and the fitness value is the only information available to the GA. The strings with large fitness values offer better solutions to the problem and have a higher probability of being selected [18]. Therefore, the string evaluation “fitness function” of the GA methodology for the reconfiguration problem can be obtained using the fitness described by the following equations:

$Fitness = \frac{1}{Ploss}$ ….. (8) or

$Fitness = \frac{1}{Ploss+1}$ ….. (9)

According to the above equations, the less loss in the distribution system, the higher the fitness value. Thus, we can take P_{Loss} as the fitness function in the GA.

C. String selection

There used two selection methods, with "Elitism Techniques" in both methods:

1. Roulette Wheel Selection(RSW) [19]

The simple GA utilizes the Roulette Wheel Selection (RWS) as a string selection strategy, while the proposed method uses the remainder stochastic sampling with replacement (Ranking – Based Selection) to improve the convergence characteristics. The procedure can be summarized as follows:

- Sum up the fitness values of each string (fi).
- Calculate the following probability. $Pselect_i = f_i / \sum_{i=1}^{ns} f_i$ ….. (10)
- The expected number of strings (e_i) can be calculated using the following equation.

$$e_i = (Pselect).ns \quad \text{….. (11)}$$

Where, ***ns***: the number of strings

Each string is reproduced more by using the fraction part of ei as the weight for the roulette wheel selection. Namely, the method uses RWS only for the fraction part of ei. The procedure is repeated until the number of strings reaches ns.

2. Tournament Selection

The fitness proportionate methods described above require two passes through the population at each generation: one pass to compute the mean fitness (and, for sigma scaling, the standard deviation) and one pass to compute the expected value of each individual. Rank scaling requires sorting the entire population by rank a potentially time consuming procedure. Tournament selection is similar to rank selection in terms of selection pressure, but it is computationally more efficient and more amenable to parallel implementation. Two individuals are chosen at random from the population. A random number r is then chosen between 0 and 1. If $r < k$ (where k is a parameter, for example 0.75), the fitter of the two individuals is selected to be a parent; otherwise the less fit individual is selected. The two are then returned to the original population and can be selected again [19, 20, and 21].

D. String Operation:

1. Crossover

Crossover operation exchanges partial radial networks at the boundary of the section of the crossover point. The crossover operation takes two parents switch vectors (two chromosomes) and cuts at a randomly selected point. The two parents are crossed over at that point and two offspring are produced.

An example of this operator is shown in figure (4). After applying the crossover operator it is expected that the resulting string sometimes violate the constraints and need be modified. The modification take place by one of the following [6, 22]:

i. Change the crossover point until a string, which does not violate the constraints is generated.

ii. Modify string after the string operation.

Here, (i) is utilized as the modification of the string. Moreover, the fitness values of strings that violate power source limit, voltage, and current constraints are modified.

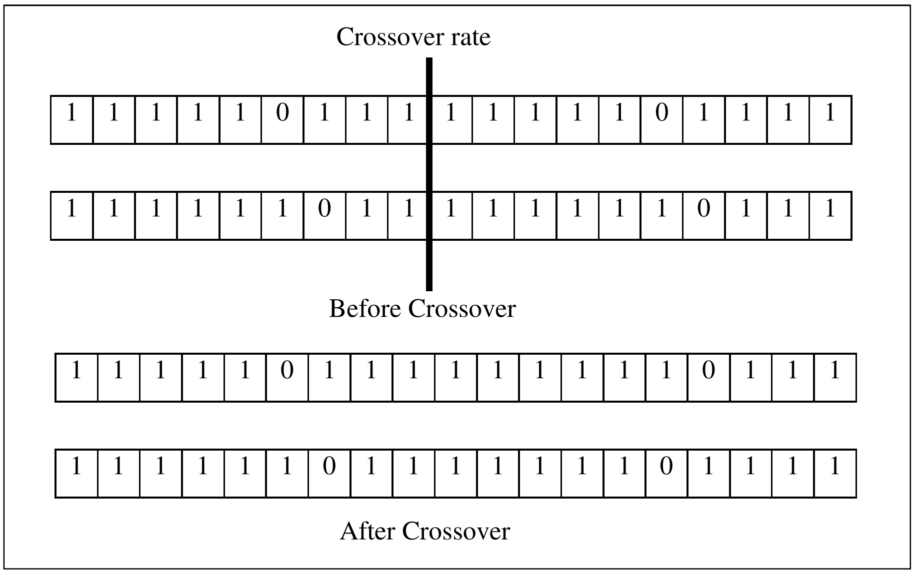

Figure – 4: the Crossover of Two-Switch Vector

2. *Mutation*

Mutation is a bit exchange at a string position .Random alteration of genes in a string or values of a string may occur. For binary coded string, a mutation represents a simple bit change and it is provides random excursion into new parts of the search space [23].

E. *Stopping criteria (Termination)*

There are many ways to terminate a GA, many of them similar to termination conditions used for conventional optimization algorithms. A iteratively performs the operations on each generation of individuals to produce new generation until some stopping criterion is satisfied [20]. The stopping criterion can be stated in either of following ways:

1. The algorithm has reached the maximum number of generations or specified fitness value.
2. When all chromosomes in a generation are identical.
3. Taking the best solution after performing a fixed number of evaluations.

Here, (1) is utilized as the termination of the GA. When the user input maximum allowable number of generation for the GA is reached, the best solution found.

F. The GA to find optimal topology is as follows:

1. Create randomly an initial population of open switches positions for the distribution system.
2. Evaluate each distribution system topology (chromosome) by running the load flow program. The fitness of an individual is determined by the active power loss.
3. Select parent's forms from the population for reproduction based on their fitness.
4. Apply search operator (crossover, mutation) to parents and generate offspring, which form the next generation.
5. Go to step 2, if the some criterion is not reached.

In this study, the GA is successfully applied to the loss minimum reconfiguration problem.

Simulation Results

The program was designed to solve the network reconfiguration problem, is divided in two solutions, which are load flow and optimization. The main program consists of three stages or sub-programs, Simplified solution method of load flow, Fast decoupled method and Genetic algorithm. The first and second sub-programs are used for load flow of distribution system. These sub-programs, which have different accuracy, are used to save time. The simplified, which is an approximate solution, is used when most reconfigurations are accepted and the fast decoupled, which is an exact solution, is used when solution near the optimum configuration. Third sub-program determines the global optimum solution to the network reconfiguration problem by using the genetic algorithm technique.

A. *Optimization program*

The main program represent optimum network reconfiguration for genetic algorithm shown in figure (5), included two sub-program , the first sub-program to calculate power losses and given the tie line (open switch), the second sub-program to calculate crossover and mutation. In summary the steps of the program are as follow:

1. Input data a real parameter of genetic algorithm, number of generation, population size, the proportion ratio rate of crossover and mutation, the size of chromosome represented number line in the distribution system with used binary number 0 or 1.

0: represent open line.

1: represent close line.

2. String representation generation for external initial population.

3. String evaluation, to evaluate the fitness of random population (power loss), go to sub-program to calculate fitness function power losses including fast-decoupled shown in figure (6) compute by equation (9).

Fitness: represented the maximization in genetic algorithm.

Power: represented the minimization in optimum configuration.

4. Determine the best solution in the generation with used elitism techniques.

5. String selection, in the executing start program present the massage to choice the selection method.

0: if used roulette wheel selection method.

1: if used tournament selection method.

6. String operation, go to sub-program to calculate the crossover and mutation.

7. If the number of generation equal maximum number:

a. Display results optimum switch, run time, maximum fitness, minimum power loss.

b. Plot of genetic algorithm with two dimensions (x, y).

X: represented number of generation.

Y: represented fitness maximization.

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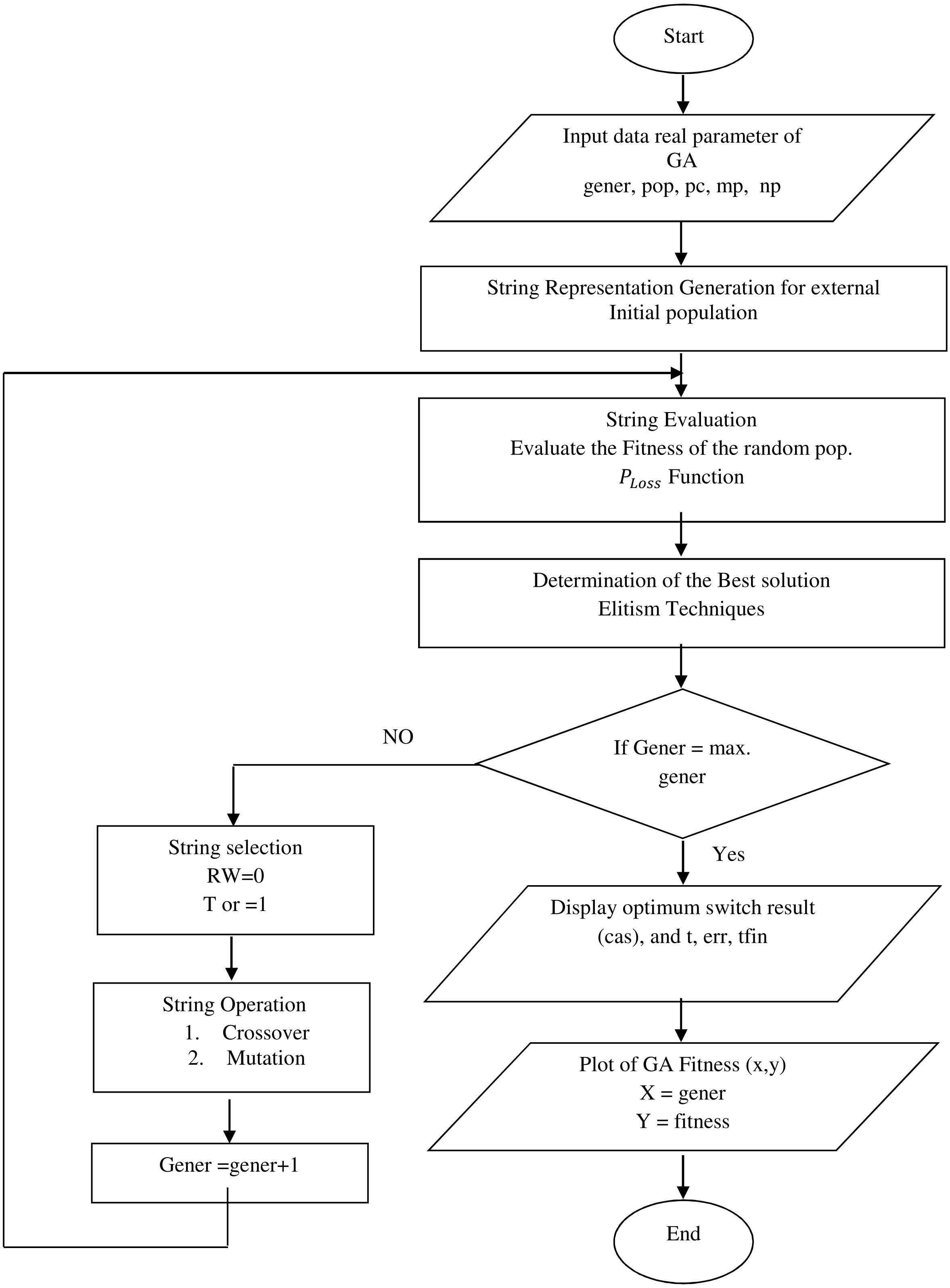

Figure-5: Flow chart optimization program for Network Reconfiguration

Where:
c: Number of sectionalizing switches, cas: Switches between two bus is open
d: Total number of switch, err : Value of the fitness function
gener: Number of generation, Kw: Number of tie switches
P: Active power (KW), Q : Reactive power (KVAR), Qc : Capacitor (KVAR)
no1: Represent to the sending end bus, no2: Represent to the receiving end bus
np: Number of branch, Nt: Degree of the differential equation
Pc: Crossover probability, Pm: Mutation probability, Pop: The population size

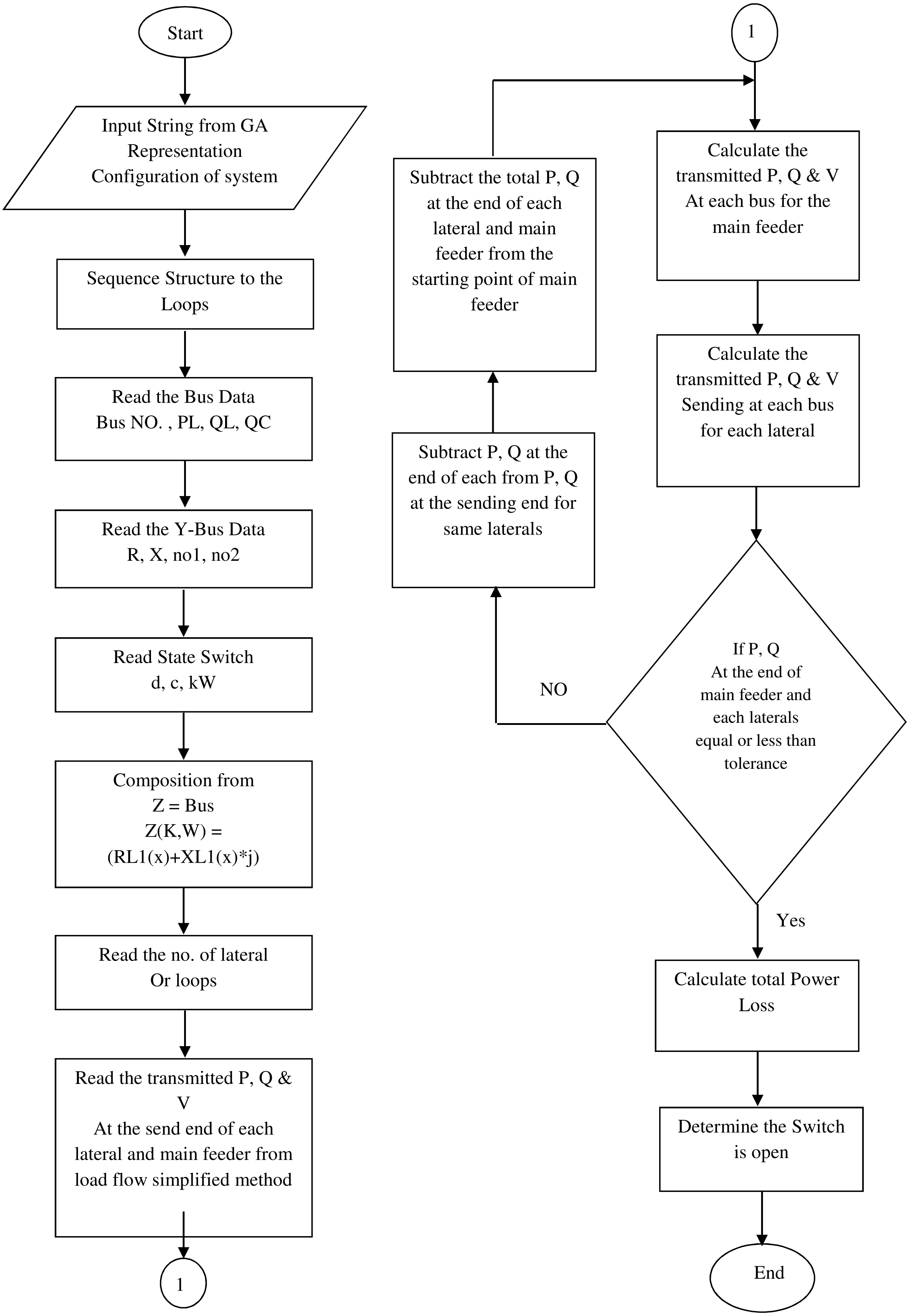

Figure-6: Flow chart to clearness the block in optimization program evaluates fitness power loss

B. Test System

For the optimization program to be effective a large number of data about the distribution network is required. The input data in a record file for each feeder are line and load data. Line data consists of a list of line numbers, the receiving and sending bus number and the distance data (resistance and reactance) between them. Load data is entered as a real (kW), reactive (kVAR) powers and fixed capacitors (kVAR) of the sending bus.

The power supply to the city of Baghdad is provided basically from two main substations of 400/132 kV (Baghdad East and Baghdad west), which in turn supply many substations of 132/33 kV (or 132/33/11 kV) distributed geographically throughout the city.

A schematic diagram showing the structure of this system is given in Fig. (7). These 132/33 kV substations in turn provide power supply to a very large number of 33/11 kV substations. Most of these 33/11 kV substations are equipped with two transformers of 31.5 MVA each. The 11 KV distribution feeders are supplied from the low voltage bus-bars of these substations using underground cable and / or over-head line systems.

Each 11 KV feeder provides the supply to a large number of 11 / 0.4 KV transformers. One such substation was selected located in Palestine Street.

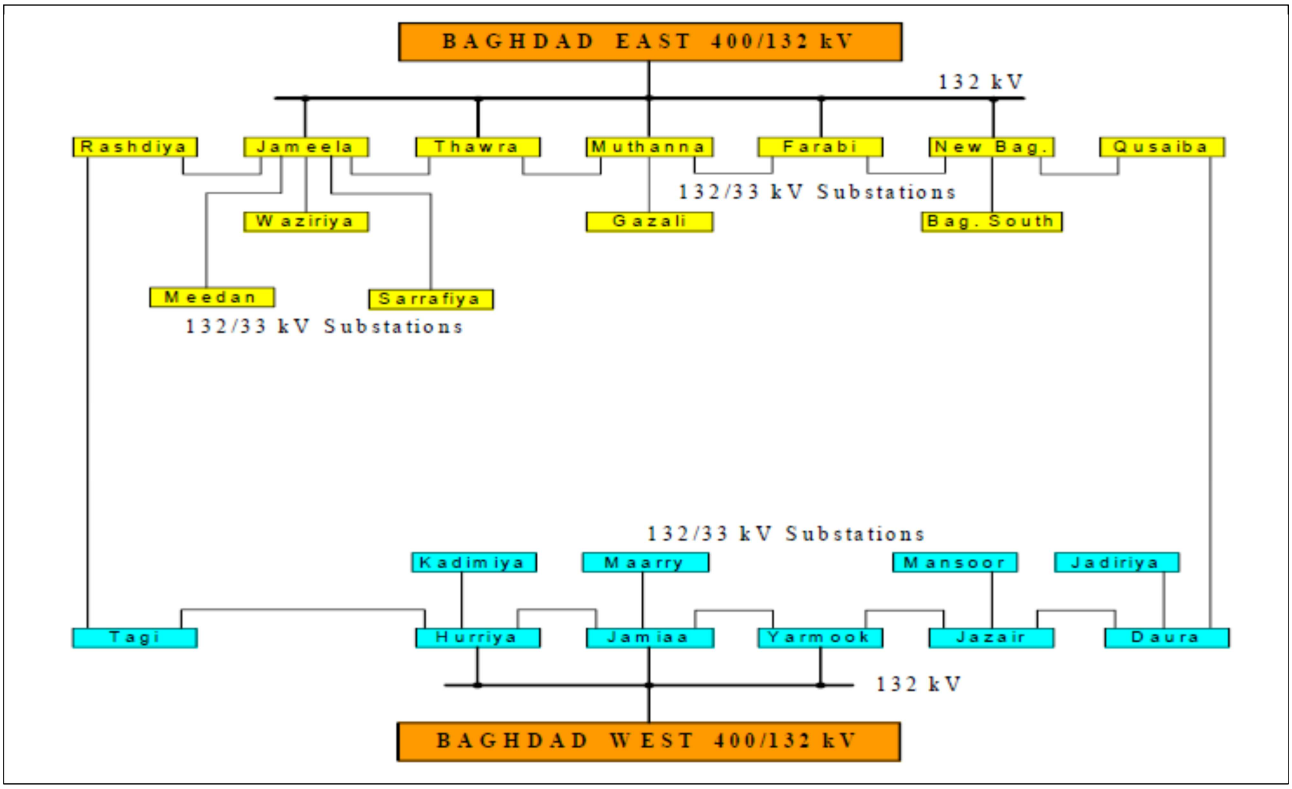

Figure-7: Diagram for Baghdad City Supply Structure

The reasons for selecting this sit and this type of substation are: -

1) The distribution system is properly designed and implemented by using under – ground cables by Messers Siemens. Co.

2) A room is available at the low voltage side of substation for taking the measurements.

A typical single line diagram of this substation is shown in Figure (8). The test is 11 KV system with 48 buses, main feeder, 6 laterals, and 7 capacitor in buses location (9, 13, 24, 32, 36, 42 and 48), size of capacitor (100, 75, 100, 200, 200, 350 and 200 kVAR) respectively, (1, 80, 1, 2, 2, 3.7 and 2 μF) respectively.

The schematic diagram of test system is shown in Figure (9). The system data with power demand information are tabulated in table (1). There are two looping branches (tie lines) in the system and sectionalizing switches on every branch of the system. The results of the network configuration by used the load flow programs, simplified method and fast-decoupled shown table (2). The results after network reconfiguration by using genetic algorithm, the diagram becomes shown Figure (10), the data table shown table (3) and load flow output and power loss shown table (4). By implementing the program of Genetic Algorithm (GA), the global optimum configuration for loss reduction is obtained. In GA program, used two methods selection, roulette wheel method and tournament method with elitism technique, results comparison of two selections and real parameter in genetic algorithm, a one-point crossover, mutation operator is used. The result of Convergence characteristics, number of generation with fitness function of genetic algorithm for roulette wheel selection method shown Figure (11), for tournament method selection shown (12).

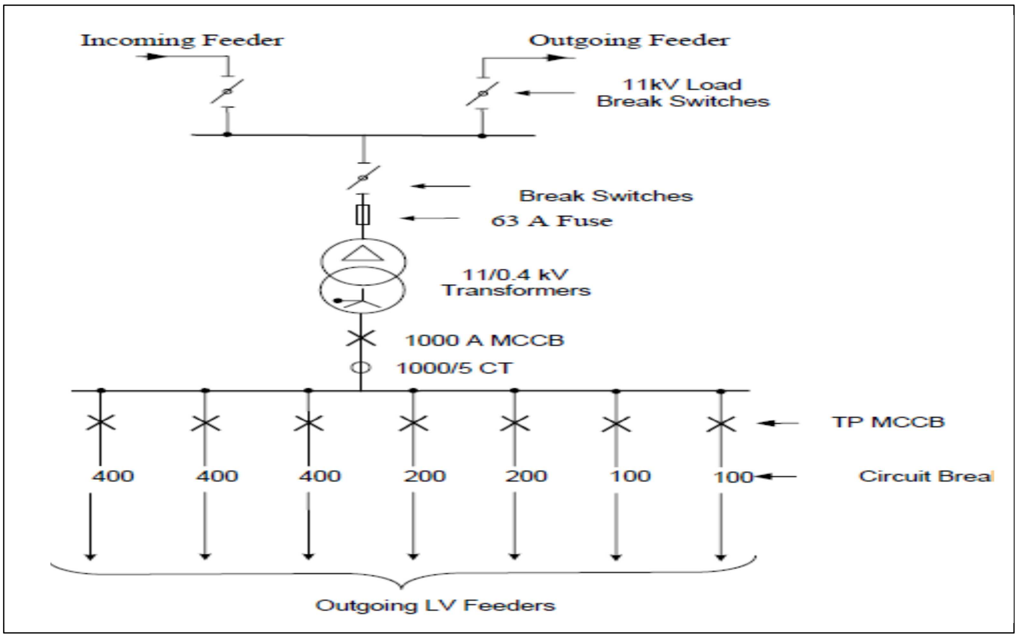

Figure-8: Single Line Diagram of Typical 11/0.4 kV Transformer Substation

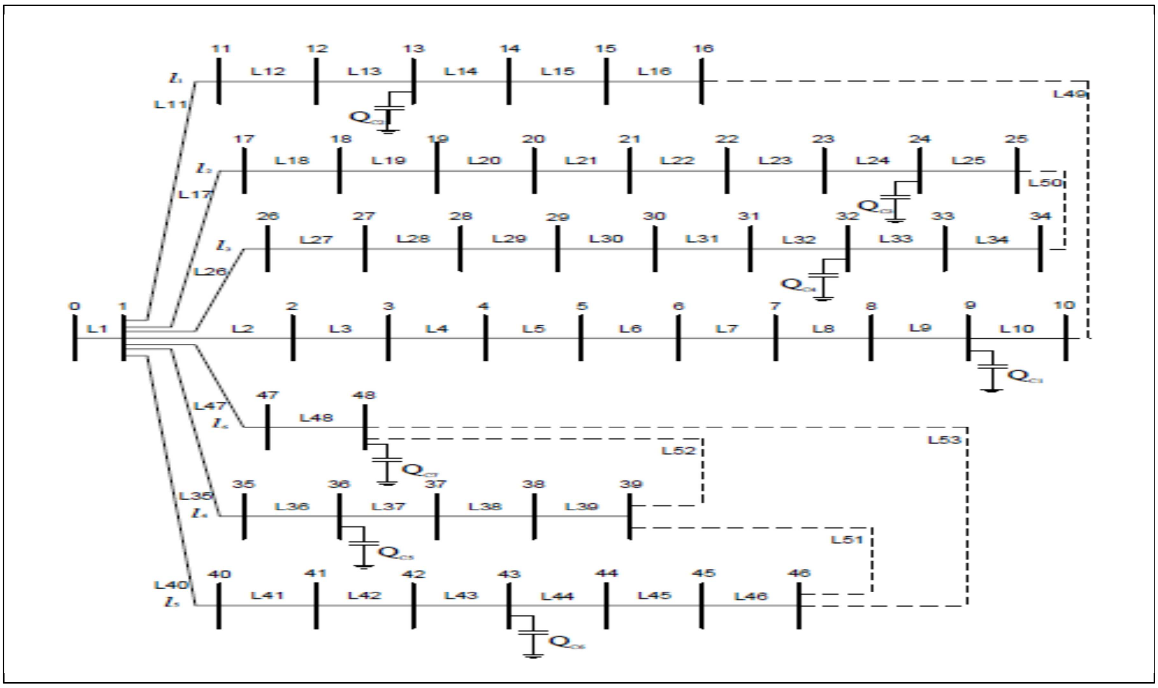

Figure-9: Diagram for Practical network before Reconfiguration

Table -1: Network Data for Practical Example at (11kV) Rated voltage before reconfiguration

Line No.	Line State	Send. Bus	Reci. Bus	Line Resis. Ω	Line Reac. Ω	Rec. End Bus Load		
						P kW	Q kvar	Qc Kvar
1	1	0	1	0.0031	0.0022	0.00	0.00	0.00
2	1	1	2	0.0031	0.0022	969.67	469.63	0
3	1	2	3	0.7440	0.5470	401.24	194.33	0
4	1	3	4	0.8680	0.6380	100.31	48.582	0
5	1	4	5	0.4340	0.3190	401.24	194.33	0
6	1	5	6	0.1628	0.1200	1003.1	485.83	0
7	1	6	7	0.6200	0.4600	936.24	453.47	0
8	1	7	8	0.5890	0.4330	735.61	356.28	0
9	1	8	9	0.3570	0.2620	869.36	521.05	100
10	1	9	10	1.0186	1.0137	1270.6	615.38	0
11	1	1	11	0.0434	0.0319	922.05	446.57	0
12	1	11	12	1.0171	1.0125	1276.6	618.33	0
13	1	12	13	0.4340	0.3190	638.34	384.16	75
14	1	13	14	1.0403	1.0293	2908.1	1408.4	0
15	1	14	15	0.3660	0.2690	922.05	446.57	0
16	1	15	16	0.1860	0.1370	425.56	48.706	0
17	1	1	17	0.0233	0.0171	1791.4	867.62	0
18	1	17	18	0.3880	0.2880	1264.5	612.44	0
19	1	18	19	0.2790	0.2050	948.40	459.33	0
20	1	19	20	0.5520	0.4050	421.51	204.51	0
21	1	20	21	0.3970	0.2920	1896.8	918.66	0
22	1	21	22	1.0233	1.0171	1686.1	816.59	0
23	1	22	23	0.0780	0.0570	316.13	153.11	0
24	1	23	24	0.9900	0.7300	1053.7	610.36	100
25	1	24	25	0.9900	0.7300	632.26	306.22	0
26	1	1	26	0.0160	0.0120	559.31	270.88	0
27	1	26	27	0.3720	0.2730	838.97	406.33	0
28	1	27	28	0.4400	0.3230	1258.4	609.49	0
29	1	28	29	0.3660	0.2690	1258.4	609.49	0
30	1	29	30	0.4500	0.3300	1817.7	880.38	0
31	1	30	31	0.2950	0.2160	2237.2	1083.5	0
32	1	31	32	0.2850	0.2100	1817.7	1080.3	200
33	1	32	33	0.4590	0.3370.	1957.5	948.10	0
34	1	33	34	1.0217	1.0160	1957.5	948.10	0
35	1	1	35	0.0372	0.0273	607.95	294.44	0
36	1	35	36	0.2880	0.2120	1925.1	1132.4	200
37	1	36	37	0.4190	0.3080	303.97	147.22	0
38	1	37	38	0.4030	0.2960	3343.7	1619.4	0
39	1	38	39	0.8680	0.6380	222.91	1079.6	0
40	1	1	40	0.0620	0.0456	719.40	348.40	0
41	1	40	41	0.2110	0.1550	1726.5	836.2	0
42	1	41	42	0.2170	0.1600	1582.6	766.53	0
43	1	42	43	0.4190	0.3080	3597.0	2092.1	350
44	1	43	44	1.0388	1.0285	2877.6	1393.6	0
45	1	44	45	0.6360	0.4670	3884.7	1881.4	0
46	1	45	46	1.0140	0.6105	4677.4	2265.4	0
47	1	1	47	0.1023	0.0752	1491.5	722.36	0

48	1	47	48	0.0285	0.0210	1750.8	1047.9	200
49	0	10	16	0.0388	0.0285			
50	0	25	34	0.0118	0.0087			
51	0	39	46	0.0481	0.0353			
52	0	39	48	0.0837	0.0615			
53	0	46	48	0.0357	0.0262			

Table -2: Load Flow output by Fast Decoupled method for data in Table (1) before reconfiguration

Send. End Bus	**Rec. End Bus**	**Power between Sen. & Rec. Bus**		**Voltage at Send. Bus (V)**
		Real Power (kW)	Reactive Power (kvar)	
0	1	66012.260	32879.732	11000.000
1	2	6821.3233	3288.0051	10999.974
2	3	5718.5978	2769.893	10999.498
3	4	5317.1036	2575.3777	10999.423
4	5	5216.5421	2526.6117	10998.854
5	6	4815.1756	2332.1901	10998.575
6	7	3812.0211	1846.3297	10998.479
7	8	2875.6861	1392.7914	10998.186
8	9	2140.0174	1036.4709	10998.186
9	10	1270.6317	615.40471	10997.883
10	-	0.000000	0.000000	10997.709
1	11	7092.7440	3277.7640	10999.936
11	12	6171.3704	2831.8466	10999.105
12	13	4894.2879	2213.1288	10998.848
13	14	4255.8374	1903.8867	10998.267
14	15	1347.6295	495.28279	10998.210
15	16	425.56528	48.706207	10998.202
16	-	0.0000000	0.0000000	10999.945
1	17	10010.907	4848.4980	10999.974
17	18	8220.3939	3981.5795	10999.552
18	19	6955.5904	3368.9410	1099.313
19	20	6007.0506	2909.5078	10998.904
20	21	5585.3354	2705.2116	10998.631
21	22	3688.4060	1786.4557	10998.122
22	23	2002.2169	969.72449	10998.103
23	24	1686.0797	816.61216	10997.122
24	25	632.27100	306.22297	10997.103
25	-	0.000000	0.000000	10997.820
1	26	13703.182	6636.7590	10999.974
26	27	13146.499	6367.8125	10999.947
27	28	12306.872	5960.9990	10999.344
28	29	11047.742	5351.0008	10998.677
29	30	9788.8308	4741.1667	10998.178
30	31	7970.6197	3860.4580	10997.635
31	32	5733.1744	2776.7649	10997.346
32	33	3915.3078	1896.3084	10997.144
33	34	1957.6370	948.14774	10996.923
34	-	0.00000000	0.00000000	10996.653
1	35	8409.9710	4073.1360	10999.974
35	36	7802.5193	3779.0584	10999.935
36	37	5877.1664	2846.5227	10999.658

37	38	5573.0437	2699.1932	10999.354
38	39	2229.1930	1079.6593	10999.078
39	-	0.0000000	0.0000000	10998.839
1	40	19065.6070	9233.8960	10999.828
40	41	18350.5950	8889.0262	10999.351
41	42	16623.2920	8052.2736	10998.906
42	43	15039.9851	7285.2874	10998.129
43	44	11441.9818	5542.4514	10996.530
44	45	8562.9636	4147.3780	10995.858
45	46	4677.6885	2265.53439	10995.301
46	-	0.000000	0.0000000	10999.880
1	47	3242.3990	1570.36300	10999.974
47	48	1750.8974	847.996249	10999.880
48	-	0.000000	0.0000000	10999.968

Total power loss=10593.47 Watt

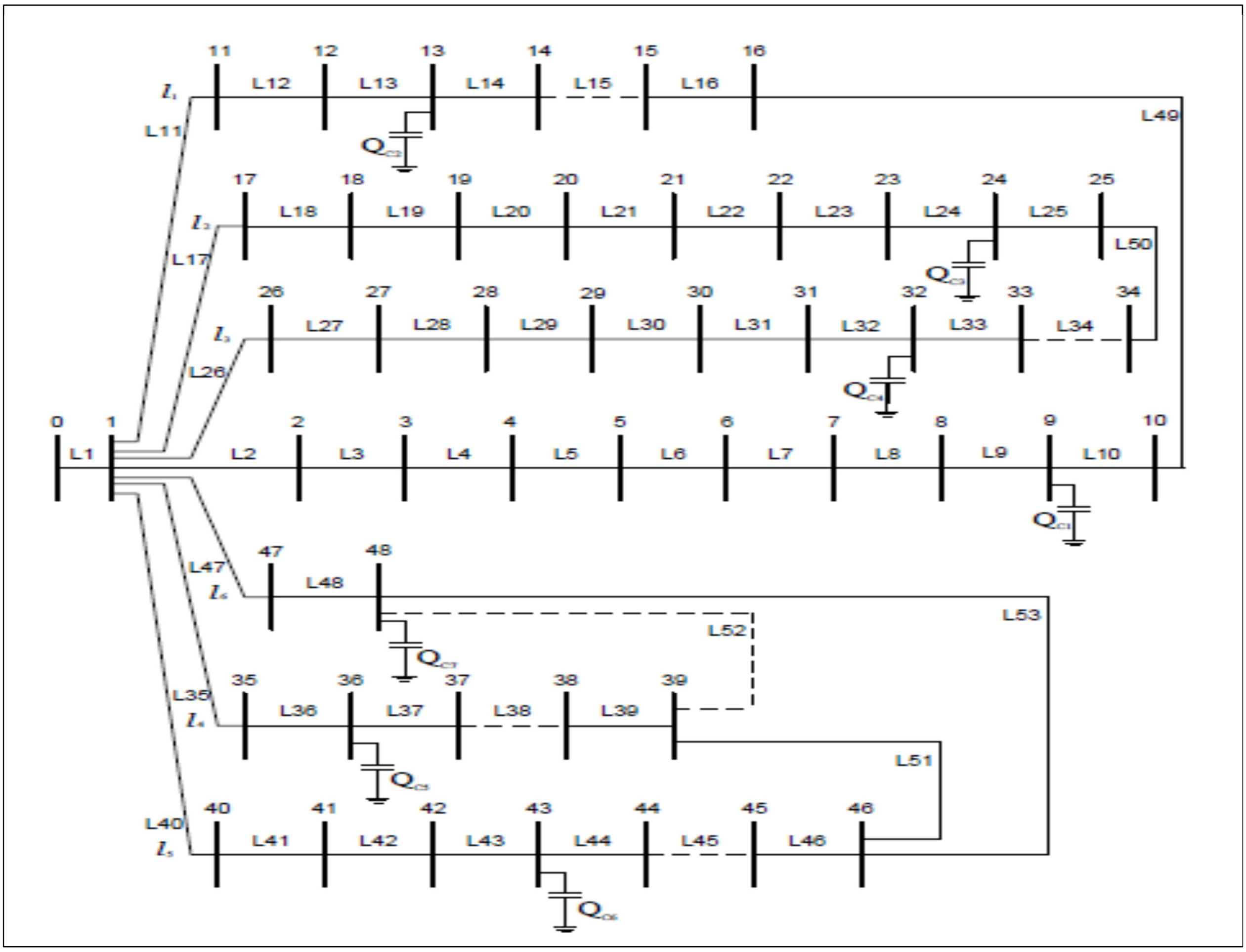

Figure -10: Diagram for Practical Network after Reconfiguration

Table -3: Network Data for Practical Example at (11kV) Rated Voltage after Reconfiguration

Line No.	Line State	Send. Bus	Rec. Bus	Line Resis. Ω	Line Reac. Ω	Rec. End Bus Load		
						P kw	Q kvar	Qc kvar
1	1	0	1	0.0031	0.0022	0.0000	0.0000	0

2	1	1	2	0.0031	0.0022	969.67	469.63	0
3	1	2	3	0.7440	0.5470	401.24	194.33	0
4	1	3	4	0.8680	0.6380	100.31	48.582	0
5	1	4	5	0.4340	0.3190	401.24	194.33	0
6	1	5	6	0.1628	0.1200	1003.1	485.83	0
7	1	6	7	0.6200	0.4600	936.24	453.47	0
8	1	7	8	0.5890	0.4330	735.61	356.28	0
9	1	8	9	0.3570	0.2620	869.36	521.05	100
10	1	9	10	1.0186	1.0137	1270.6	615.38	0
16	1	16	15	0.1860	0.1370	922.05	446.05	0
11	1	1	11	0.0434	0.0319	922.05	446.57	0
12	1	11	12	1.0171	1.0125	1276.6	618.32	0
13	1	12	13	0.4340	0.3190	638.34	384.16	75
14	1	13	14	1.0403	1.0296	2908.0	1408.4	0
17	1	1	17	0.0233	0.0171	1791.4	867.62	0
18	1	17	18	0.3880	0.2850	1264.5	612.44	0
19	1	18	19	0.2790	0.2050	948.40	459.33	0
20	1	19	20	0.5520	0.4050	421.51	204.14	0
21	1	20	21	0.3970	0.2920	1896.8	918.66	0
22	1	21	22	1.0233	1.0171	168.04	816.59	0
23	1	22	23	0.0780	0.0570	316.13	153.11	0
24	1	23	24	0.9900	0.7300	1053.7	610.36	100
25	1	24	25	0.9900	0.7300	632.26	306.26	0
50	1	25	34	0.0118	0.0087	1957.5	948.10	0
26	1	1	26	0.0160	0.0120	559.31	270.88	0
27	1	26	27	0.3720	0.2730	838.97	406.33	0
28	1	27	28	0.4400	0.3230	1258.4	609.49	0
29	1	28	29	0.3660	0.2690	1258.4	609.49	0
30	1	29	30	0.4500	0.3300	1817.7	880.38	0
31	1	30	31	0.2950	0.2160	2237.5	1083	0
32	1	31	32	0.2850	0.2100	1817.7	1080.3	200
33	1	32	33	0.4590	0.3370	1957.5	948.10	0
35	1	1	35	0.0372	0.0273	607.95	294.44	0
36	1	35	36	0.2880	0.2120	1925.1	1132.4	200
37	1	36	37	0.4190	0.3080	303.97	147.22	0
40	1	1	40	0.0620	0.0456	719.40	348.42	0
41	1	40	41	0.2110	0.1550	1726.5	836.22	0
42	1	41	42	0.2170	0.1600	1582.6	766.53	0
43	1	42	43	0.4190	0.3080	3597.1	2092.1	350
44	1	43	44	1.0388	1.0285	2877.6	1393.6	0
47	1	1	47	0.1023	0.0752	1491.5	722.36	0
48	1	47	48	0.0285	0.0210	1750.8	1047.9	200
53	1	48	46	0.0357	0.0262	4677.4	2265.4	0
46	1	46	45	1.0140	0.6105	3884.7	1881.4	0
51	1	46	39	0.0481	0.0353	222.91	1079.6	0
39	1	39	38	0.8680	0.6380	3343.7	1619.4	0
15	0	14	15	0.3660	0.2690			
34	0	35	34	1.0217	1.0160			
38	0	37	38	0.4030	0.2960			
45	0	44	45	0.6360	0.4670			
52	0	39	48	0.0837	0.0615			

Table-4: Load Flow Output by Fast Decoupled method for data in Table (3) After Reconfiguration by using Genetic Algorithm

Send. End Bus	Rec. End Bus	Power between Sen. & Rec. Bus		Voltage at Send. Bus (V)
		Real Power (kW)	Reactive Power (kvar)	
0	1	66012.260	32879.732	11000.000
1	2	6670.4227	3408.7711	10999.974
2	3	7563.5551	3663.6864	10999.948
3	4	7161.8748	3469.0341	10999.255
4	5	7061.1095	3420.1182	10998.488
5	6	6659.6426	3225.6229	10998.110
6	7	5656.4590	2739.7365	10997.977
7	8	4720.0135	2286.1163	10997.543
8	9	3984.2605	1929.7338	10997.200
9	10	3114.8337	1508.6374	10997.025
10	16	1844.1228	893.14903	10996.597
16	15	922.05830	446.57227	10996.555
15	-	0.0000000	0.0000000	10996.550
1	11	5745.1150	2782.4800	10999.974
11	12	5338.1484	2585.5274	10999.067
12	13	4699.6752	2276.2686	10998.782
13	14	1791.4207	867.62656	10998.124
14	-	0.0000000	0.0000000	10998.119
1	17	11968.475	6605.7960	10999.974
17	18	9473.4670	4588.7276	10999.460
18	19	8524.8095	4129.2078	10999.135
19	20	8102.8881	3924.7605	10998.555
20	21	6205.8221	3005.9018	10998.158
21	22	4519.3798	2188.9120	10997.303
22	23	4203.2296	2035.7901	10997.259
23	24	3149.2710	1525.2905	10996.746
24	25	2516.9038	1218.9966	10996.361
25	34	559.31300	270.88803	10996.357
34	-	0.0000000	0.0000000	10996.356
1	26	11745.563	5688.6480	10999.974
26	27	10956.666	5306.9262	10999.433
27	28	9697.6772	4697.0316	10998.839
28	29	8438.8759	4087.2744	10998.401
29	30	6620.7788	3206.6485	10997.934
30	31	4383.3968	2123.0019	10997.693
31	32	2565.5709	1242.5747	10997.539
32	33	607.95014	294.44410	10997.394
33	-	0.0000000	0.0000000	10997.391
1	35	2837.0950	1374.0690	10999.974
35	36	1023.3868	495.64953	10999.869
36	37	719.40732	495.64953	10999.816
37	-	0.0000000	0.0000000	10999.811
1	40	10503.327	5086.9900	10999.974
40	41	9549.5279	4625.2624	10999.681
41	42	7966.6360	3858.5785	10999.425
42	43	4369.3347	2116.2590	10999.013
43	44	1491.5023	722.36870	10998.403

44	-	0.0000000	0.0000000	10998.384
1	47	15371.275	8416.3030	10999.974
47	48	13620.312	7568.2536	10999.924
48	46	8942.7810	5302.8111	10999.861
46	45	1490.4501	721.71573	10998.743
45	-	0.0000000	0.0000000	10998.734
46	39	3566.6350	2699.0600	10998.743
39	38	3343.7200	1619.4400	10998.702
38	-	0.0000000	0.0000000	10998.685

Total power loss=8976.277Watt

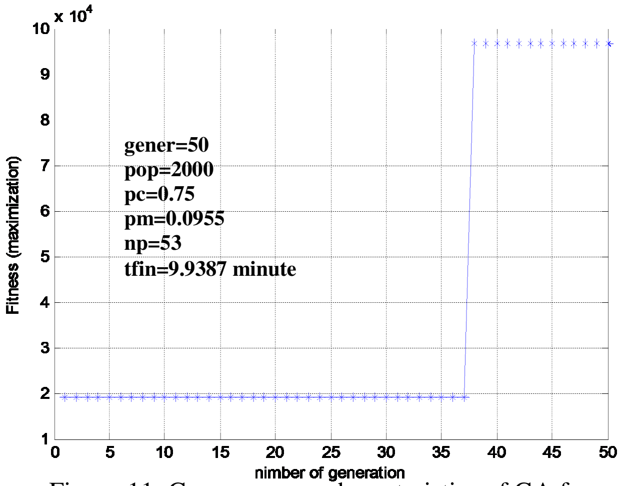

Figure-11: Convergences characteristics of GA for Roulette Wheel method

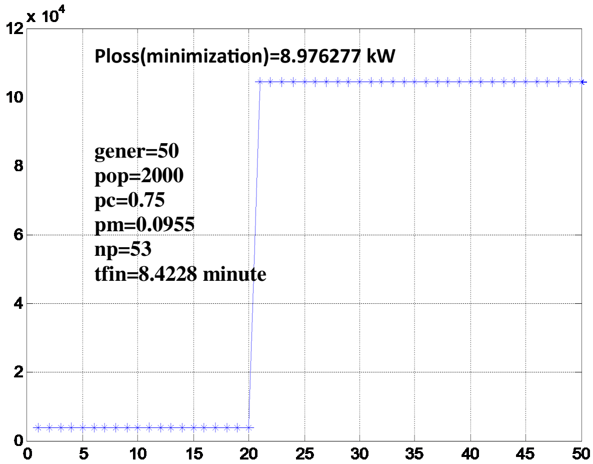

Figure-12: Convergences characteristics of GA for Tournament method

Discussion

Although, the results show that the real power losses seem low, the systems keep under load balancing. In distribution system of Iraq, most of the switches are manual and have no data acquisition facilities. Therefore, it is difficult to use program for on-line applications. The quality of the optimum configuration and computational speed depend on several variables including a real parameter in genetic algorithm, number of generation, population size, proportion ratio rate of crossover and mutation, number of lines sectionalizing switches and tie switches, selection method, the method used to calculate fitness function. So that, experience distribution engineering's needed.

The initial population represent important factor in the program genetic algorithm to arrive to the best fitness function and low time executing process of the program. The comparison between two selection methods in genetic algorithm presents the same results in optimum configuration (power losses) and the tie lines (open switches), but different in execution time of the program and to arrive the best fitness function. The results in table (5), presents the roulette wheel selection method more speed than the tournament selection method to arrive the best fitness and end program. The comparison between the results which are obtained in this study with the results of reference [17], show that the percentage reduction of losses for reference is 0.41%, and for this study are 7.7%. The processes and calculation are repeated for 50% and 75% of loads in distribution network reconfiguration of practical 48-bus test system in figure (5) the results shown in tables (6) and (7).

Table -5: Distribution Network Reconfiguration (DNRC) Results of practical 48-Bus test System

Radial Network	Initial Network	GA for RW Selection method	GA for Tor Selection method
Open Switches (Tie Line)	49	15	15
	50	34	34
	51	38	38
	52	45	45
	53	52	52
Power loss (kW)	10.59347399	8.976277442	8.976277442
Run-time tfin(minute)	-	4.7253	9.7833

Table -6; Distribution Network Reconfiguration (DNRC) Results of practical 48-Bus test System at load level 50%.

Radial Network	Initial Network	GA for RW Selection method	GA for Tor Selection method
Open Switches (Tie Line)	49	15	15
	50	34	34
	51	38	38
	52	45	45
	53	52	52
Power loss (kW)	2.5964	2.1945	2.1945
Run-time tfin(minute)	-	9.428	10.795

Table -7: Distribution Network Reconfiguration (DNRC) Results of practical 48-Bus test System at load level 75%.

Radial Network	Initial Network	GA for RW Selection method	GA for Tor Selection method
Open Switches (Tie Line)	49	15	15
	50	34	34
	51	38	38
	52	45	45
	53	52	52
Power loss (kW)	5.8942	4.9857	4.9857
Run-time tfin(minute)	-	5.4675	10.852

Conclusions

Based on the analysis and results presented in this paper the following conclusions are drawn:

1. The reconfiguration strategy can synthesize a highly non-linear optimization process, which involves two stages. In the first stage, the load profile is determined from a limited number of calculated data. In the second stage, the optimal configurations are found from the load profile identified in the first stage.

2. Two efficient load flow methods with different accuracy are employed. The simplified method, which an approximate method is used at starting for implementing program. The other is the fast-decoupled method, which is an exact method used at the sub-program of the program.

3. This work has proposed a systematic methodology for distribution network minimum loss reconfiguration analysis the methodology contain effective determination of minimum power loss configuration using genetic algorithm.

4. GAs, which is based on the laws of natural selection and survival of the fittest, has been used successfully to reduce power loss considering balanced condition and various load characteristics. Because GAs reaches quickly the region of the optimal solutions and it's accuracy for two reasons:
- GAs avoid local minima by searching in several regions (working with a population of solutions) to arrive global minima.
- The only information they need is some performance value that determines how good a set of switches is (no gradient information).

5. The initial population represent important factor in the program genetic algorithm to arrive to the best fitness function and low time executing process of the program.

6. Two selection methods used in genetic algorithm roulette wheel selection method and tournament selection method, with elitism technique. The comparison between two selection methods in genetic algorithm presents the same results in optimum configuration (power losses) and the tie lines (open switches), but different in the executing time of the program and to arrive the best fitness function. The results presents the roulette wheel selection method more speed than the tournament selection method to arrive the best fitness and the executing time of the program.

7. The proposed approach requires much less computation time compared with that for an optimization process. Therefore, this method is expected to be applied to the on-line real time feeder reconfiguration problem.

8. The simulation of the proposed approach has been developed using a MATLAB version programming language applicable for the studied theoretically and practically. Test system shows the expert system to have efficient and quite satisfactory results.

References

[1] H. Kim, Y. Ko and K. H. Jung "*Artificial Neural Network Based Feeder Reconfiguration For Loss Reduction in Distribution System*". IEEE Trans. On power delivery, Vol. 8, No. 3, July. (1993).

[2] T. E. Mcdermott, I. Drezga, and R. P. Broadwater, *"A Heuristic Nonlinear Constructive Method for Distribution System Reconfiguration*". IEEE trans. On power system, Vol. 14, No. 2, May (1999).

[3] M. Kaptan, "*Optimization of Number, Location, Size, Control, Type, and Control Setting of Shunt Capacitor on Radial Distribution Feeder*". IEEE trans. on Power Apparatus and System, Vol. 103, No. 9, September (1984).

[4] Y. C. Huang, H. T. Yang, and C. L. Huang, "*Solving the Capacitor Placement Problem in a Radial Distribution System Using Tabu Search Approach*", IEEE Transactions on Power Systems, Vol. 11, No. 4, November (1996).

[5] M. E. Baran and F. F. Wu, *"Network Reconfiguration in Distribution Systems For Loss Reduction And Load Balancing*". IEEE Trans. on power delivery, Vol. 4,No.2, April (1989).

[6] K. Nara, A. Shiose, M. Kitagawa,and T. Ishihara, "*Implementation of Genetic Algorithm For Distribution Systems Loss Minimum Reconfiguration* ". IEEE Trans. on power systems, Vol. 7, No. 3, August 1992.

[7] Q. Zhou, D. Shirmohammadi, and W.-H.E. Liu, *"Distribution Feeder Reconfiguration For Operation Cost Reduction*". IEEE Trans. on power systems, Vol. 12, No. 2,May (1997).

[8] A. Saad, *"Optimal Network Reconfiguration in Electrical Power Distribution System*", M. Sc. Thesis (1999).

[9] M. A. Matos, and Paulomelo, "*Mulitobjective Reconfiguration For Loss Rreduction And Service Restoration Using Simulated Annealing*", http://power.inescn.pt/paulo/paper1.pdf. (1999).
[10] T. Ghose, S. K. Goswami, and S. K. Basu, *"Solving Capacitor Placement Problems in Distribution Systems Using Genetic Algorithm*". Taylor & Francis, Electric Machines and Power Systems, Vol. 27, pp. 429 – 441. (1999).
[11] A. Augugliaro, L. Dusonchet, M. G. Ippolito, and E. R. Sanseverino, *"Minimum Losses Reconfiguration of MV Distribution Networks Through Local Control of Tie-Switches*". IEEE Trans. on Power Delivery, Vol. 18, No. 3, July (2003).
[12] R. T. F. Ah King, B. Radha and H. C. S. Rughooputh, *"A Fuzzy Logic Controlled Genetic Algorithm Optimal Electrical Distribution Network Reconfiguration*". IEEE International Conference on Networking, Sensing & Control Taipei, Taiwan March, (2004).
[13] L. Garcia Santander, and F. Abou Chacra, *"Minimal Loss Reconfiguration Based on Simulated Annealing Meta – Heuristic*". Proceeding of the 15th International Conference on Electronics, Communications and Computers (Canaille comp 2005).
[14] R. Rajaram, K. Sathish Kumar and N. Rajasekar, *"Power system reconfiguration in a radial distribution network for reducing losses and to improve voltage profile using modified plant growth simulation algorithm with Distributed Generation (DG)"*. Energy Reports Vol. 1, pp. 116–122. (2015).
[15] Manju Mam, Leena G and N.S. Saxena, *"Distribution Network Reconfiguration for Power Loss Minimization Using Bacterial Foraging Optimization Algorithm"*. I.J. Engineering and Manufacturing, Vol. 2, pp. 18-32. (2016) in MECS (http://www.mecs-press.net) DOI: 10.5815/ijem.2016.02.03.
[16] Robert T. F. Ahking, B. Radha, and Harry C.S. Rughooputh, *“A Real-Parameter Genetic Algorithm for Optimal Network Reconfiguration".* University of Mauritius Reduit, Mauritius, (2003).
[17] R. Taleski, and D. Rajicic, "*Distribution Network Reconfiguration for Energy Loss Reduction*", IEEE Trans. on power systems, Vol. 12, No. 1, February (1997).
[18] S. Sivanagaraju and T. Ramana, "*A Simple Method for Feeder Reconfiguration and Service Restoration of Distribution Network*", Taylor & Francis, Vol. 32, No. 9, pp. 883 – 892. (2004).
[19] D. E. Goldberg, *"Genetic Algorithms in Search Optimization and Machine Learning*". Addision-Wesley Publishing Company, (1989).
[20] M. Mitchell, *"An Introduction to Genetic Algorithms"*, Massachusetts Institute of Technology, England, (1996).
[21] Mitsuo Gen, and Runwei Cheng. *"Genetic Algorithm and Engineering Optimization*". John Wiley & Sons, Inc, (2000).
[22] H. Fudou, T. Genji, Y.Fukuyama, and Y. Nakanishi, "*A Genetic Algorithm For Network Reconfiguration using Three Phase Unbalanced Load Flow"*. http://homepage2.nifty.com/fukuyama-yoshikazu/Isap97GA%20Lossmin.pdf . (1997).
[23] K. N. Miu, H. D. Chiang, and G. Darling, "*Capacitor Placement, Replacement and Control in Large – scale Distribution Systems by a GA – Based Two – Stage Algorithm*". IEEE Trans. on Power Systems. Vol. 12, No. 3, (1997).